DERIVATION OF SOLAR RADIATIVE CHARACTERISTICS IN THE ATMOSPHERE BY SEVIRI/MSG DATA

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ABSTRACT

This paper describes the approach for development of Universal Measurements Modelling Software for computationally efficient evaluation of solar radiative characteristics (both fluxes and radiances) using SEVIRI-based atmosphere parameter retrievals as input data. The software is based upon regression-type relationships between solar radiative fluxes (and/or radiances) and atmosphere parameters (primarily, cloud and aerosol characteristics, water vapour and ozone content) that can be reliably derived from SEVIRI measurements averaged over the areas of 400-2500 km^2. Main attention is focused on radiative transfer at different kinds of clouds, namely, broken (cumulus) clouds. The software may be also used to estimate radiation levels at the surface in different spectral bands, for example, in UV range.

1. INTRODUCTION

The modern methods for solar radiative fluxes operative estimates using satellite images are generally based on interpolations of the reference radiances and/or fluxes pre-calculated for plane-parallel cloud layer model. The drawbacks of the method application to the broken cloud conditions are well known and have been reported by many authors. At the same time recent progress in computing facilities enables to extend the above interpolation approach to the case of horizontally inhomogeneous 3D cloud models.

Note that the maximum spatial resolution of the modern and future instruments dedicated in particular for the global cloud monitoring (such as SEVIRI/MSG, AVHRR/NOAA, Imager/GOES) accounts depending on viewing angle for 1-3 km. In doing so inherent linear dimensions of broken clouds and/or cloud discontinuities observed from satellites at full cloud coverage are approximately of the same scale. Hence in order to design the cloud geometrical structure model eligible in the above context it is required to consider cloud parameter retrievals averaged over the area included about dozens of such cloud clusters. Therefore cloud parameters that can not be directly derived from satellite measurements should be incorporated into the model by synergetic use of data available from other instruments and/or statistical estimates for specified geographical region.

2. ATMOSPHERIC MODELS AND RADIATIVE TRANSFER CODE

In this context we use the model of broken cloud geometrical structure specified by normal random field being horizontally isotropic and limited from the bottom at definite atmosphere level. Such models are rather widely used to estimate probabilities of the clear line of sight for different directions and provide reasonable agreement between the model calculations and direct observations. Rublev et al (1992) and Geogdzhaev et al (1997) described particular implementation of the above method. The main input parameter of the model will be cloud amount that is reliably derived (at least for summer time conditions) using instruments like

SEVERI. Other geometrical parameters of the model, namely mean cloud diameter and thickness are specified on the basis of statistical data. A single realisation for the field of broken clouds on square is shown in the Fig.1. The horizontally homogeneous layer model is applied only for the case of full cloud coverage.

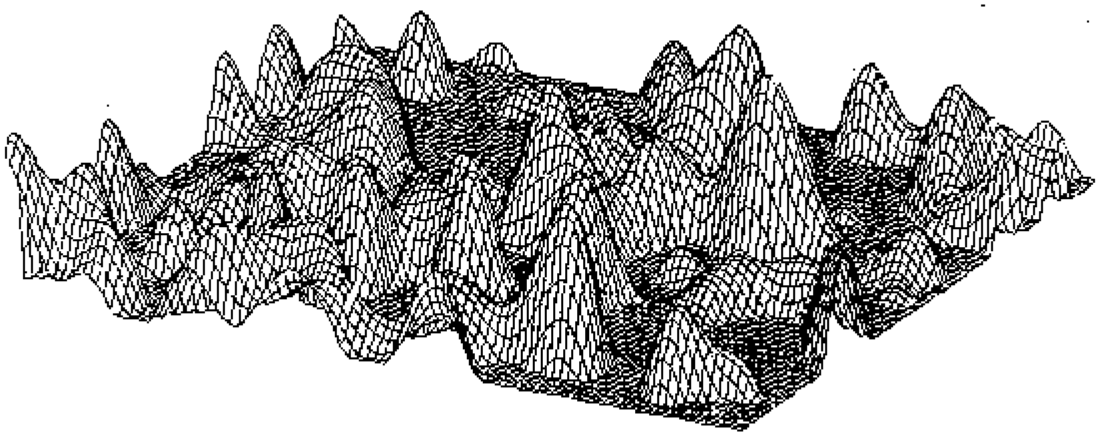

Fig.1. A single realisation of broken clouds field

The cloud optical parameters are specified by mean extinction coefficient (which can be estimated directly from SEVERI measurements), scattering phase function and single scattering albedo are evaluated using known models of the cloud particle size distribution. The procedure for extinction coefficient retrieval at different cloud amounts (see Rublev et al, 1997a) is based on an equality of calculated and measured outgoing radiances in shortwave spectral channel of the imager (e.g. SEVIRI VIS 0.6 channel).

Optical models of cirrus clouds are based on four crystal size distributions in dependence on cloudy temperature. Ice crystals are represented in the form of hexagonal prisms with given both dependencies between bottom diameter and length and between density of ice particles and prism length. The calculations of main optical characteristics directly based on the Mie theory using different effective radiuses and have good agreement to exact method presented by Fu et al (1998). Other atmospheric parameters determining solar radiative transfer out of clouds in spectral range $0.2\div5\,\mu m$ may be determined according with information received from satellite devices or taken from standard atmospheric models.

The atmospheric parameters determined in the above manner, along with solar and satellite angular co-ordinates represent initial data for the interpolation procedure to evaluate solar fluxes vertical profiles and angular distribution of the outgoing radiances. The database will be generated for this purpose. It will include the reference values of corresponding radiative parameters pre-calculated with algorithms based on 3D Monte-Carlo method. The algorithms take into account main effects of solar radiative transfer in cloudy atmosphere (including multiple scattering and line-by-line treatment of gaseous absorption). The mesh values are computed with sufficiently detailed spectral resolution for different cloud amounts, extinction coefficients as well as solar zenith angles. Thus the solar flux evaluation using SEVIRI-based cloud retrievals will be performed in two subsequent steps. The first one consists in determination of mean cloud extinction coefficient using SEVIRI-based cloud amount and the measurements in VIS-0.6 spectral channel. The second step includes the very evaluation of solar fluxes. Within both steps an interpolation over correspondent reference values is used.

The radiation codes applied for calculation of solar radiative transfer parameters have been carefully validated against ground-based measurements of surface solar downward radiation. For this purpose two different observation datasets have been considered, namely the results of measurements performed at the Meteorological Observatory (MO) of the Moscow State University (May-October 1995 and 1996) and those available from the ARESE experiment carried out in the USA in April 1994 and October 1995.

This validation exercise included the intercomparison and analysis of calculated and measured integral solar fluxes for clear-sky conditions correspondent to diverse solar zenith angles, aerosol and water vapour content, and surface state parameters. In doing so the calculated fluxes have been evaluated using the interpolation over the reference pre-calculated values of spectral upward and downward fluxes stored into relevant database. The reference data covers 99 spectral intervals (within 0.2 – 5 μm); 11 cosines of the solar zenith angle; 5 values of the surface spectral albedo; 8 values of the aerosol optical thickness; as well as 4 gradations of the water vapour total content. The interpolation procedure also included angular dependent corrections for aerosol type and ozone total content. The exercise was performed for 140 pre-selected observation session and showed good agreement of the calculated and measured downward fluxes (Chubarov et al, 1999). The detailed description of the above results is accessible via Internet (see the first reference in Bibliography section at http://www.imp.kiae.ru/crdf/).

3. UNIVERSAL MEASUREMENTS MODELLING SOFTWARE

The first experience (Rublev et al 1997b) in application of the above approach for evaluation of solar downward fluxes in cloudy conditions (using the AVHRR-based cloud parameter retrievals as input data) has shown a need to develop special service software to flexibly manage the reference data in multi-dimensional parameter space of the cloudy atmosphere. For this purpose Universal Measurement Modelling Software (UMMS) was developed. This software allows to efficiently evaluate the vertical profiles of solar (both upward and downward) fluxes and outgoing radiances in conditions of single-layer (both uniform and broken) cloudiness. The on-line version of the above system is accessible via Internet (http://www-litms.imp.kiae.ru/an.htm and http://www-lits.imp.kiae.ru/flux.htm). Two screens for this on-line software are shown in Fig.2 and Fig.3.

The UMMS database covers 111 spectral intervals within 2-5 μm range; 7 reference values of cloud amounts (from 0. to 1); 7 values of cloud extinction coefficient (from 0 to 80 km-1); 5 gradations of solar zenith angle cosine (0.25-0.85), 5 reference levels of surface spectral albedo (0-0.8) within each of 111 spectral bands. The reference data has been computed for standard mid-latitude summer temperature, humidity and trace gas profiles and aerosol model (including continental and 75% H_2SO_4 model for 0-12 and 12-20 km layers respectively, with cloud aerosol optical thickness at 0.55 μm equal to 0.226). Cloud bottom height is fixed at 1 km. The reference data of outgoing radiances includes 56 zenith viewing angle gradations correspondent to those adopted in ERBE angular radiation models and one zero azimuth angle (correspondent to the opposite-to-Sun direction) (for more details see Suttles et al., 1988). The software enables to evaluate solar fluxes for user specified spectral band (or channel) at 37 atmosphere levels from 0 to 100 km, as well as correspondent outgoing radiances at selected viewing angle. The numerical errors of the interpolation procedure (respecting the direct calculation) for the spectrally integral (0.2-5 μm) solar fluxes and outgoing radiances accounts for values less than 0.5 % and 5 % respectively. For the narrower spectral bands the accuracy is evidently lower.

4. APLLICATION OF UMMS

The UMMS system was validated using surface downward flux measurements in 0.2-5 μm and 0.30-0.38 μm spectral ranges performed during dozens of observation sessions at MO MSU coupled with synchronised AVHRR measurements over Moscow. The results of intercomparison have shown the applicability of synergetic use of UMMS and AVHRR-based cloud parameter retrievals for estimating the area-averaged downward fluxes within the above spectral bands. Furthermore the above approach has been applied in context of the UV downward radiation level estimates. Relevant methodological details and the results of method validation against synchronised ground-based measurements (14 summer time days) are presented at http://www.imp.kiae.ru/crdf/ (see reference # 4 in Bibliography section). The results of the comparison are shown in Fig.4.

On the whole, we have a good agreement. Biggest difference (this point is indicated in Fig.4 by a circle) has appeared when upper clouds shade the lower ones. There are such situations (see Fig.5) when a satellite's radiometer sees a cloud's shadow on the surface (or on the lower clouds as in our case), but, at the same time, it doesn't see the upper clouds itself. So it underestimates optical thickness of cloudiness, and as the result overestimates the calculated downward flux.

The UMMS also allows to test current angular radiation model and new ones of outgoing radiation in the mathematical simulation of radiation balance measurements without any errors connected with identification of atmospheric scenes. We have tested the ERBE models (Suttles et al., 1988) for short-wave ScaRab channel and found, for example, that for cloud amount n=0.7 the ERBE class <mostly cloudy> had more errors of anisotropy factors relatively to exact calculations than class <partly cloudy>. The other result was

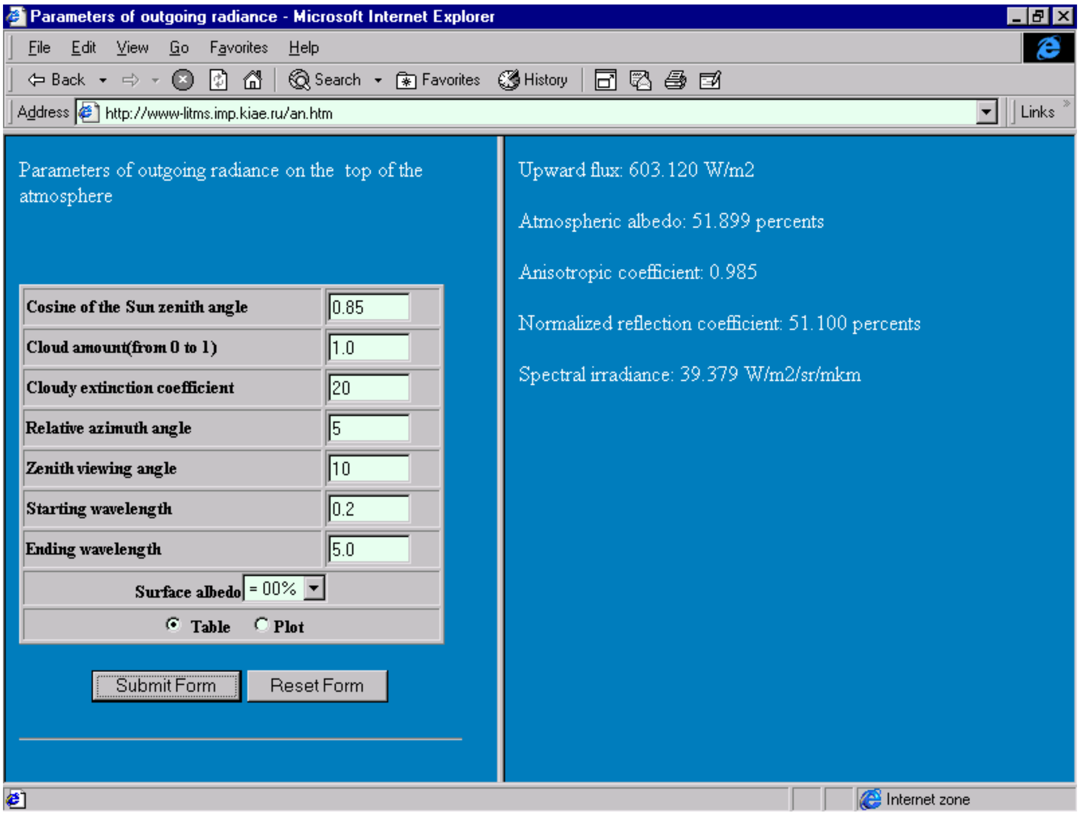

Fig. 2. Web-based software for calculation of outgoing radiance parameters on the top of the atmosphere.

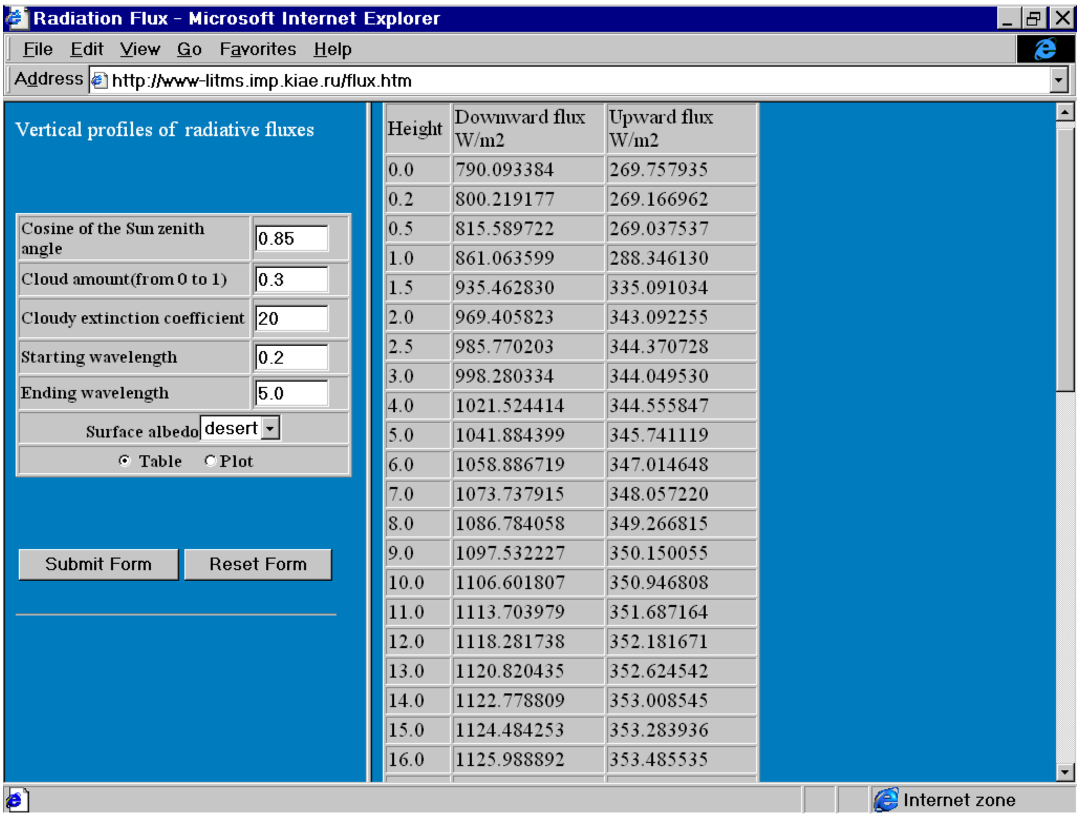

Fig. 3. Web-based software for solar fluxes vertical profiles calculation.

that for constant cloud amount the impact of cloudy cover non-uniformity on anisotropy factor was more than difference between ERBE cloudy (partly and mostly) scenes.

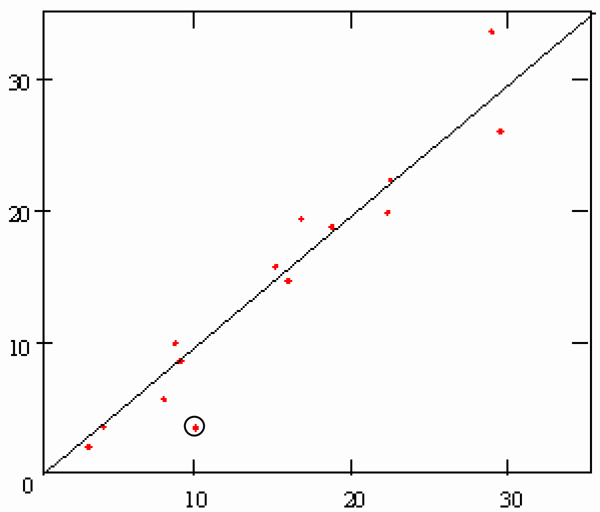

Fig. 4. Comparison between observed and calculated UV fluxes, W/m^2

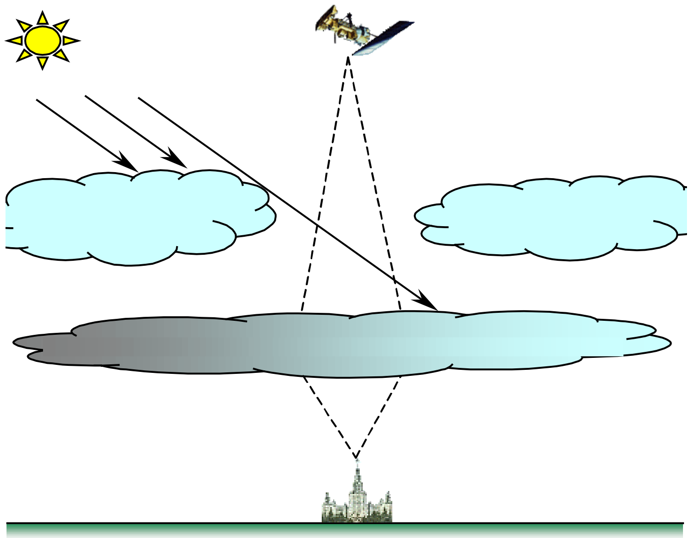

Fig. 5. Geometrical scheme explaining an appearance of rough computational errors.

5. FUTURE DIRECTIONS

It must be stressed that all above results were obtained under summer conditions for cloudless atmosphere or in presence of the only one cloud layer. In future, a field of the software applicability will be extended, particularly, up to three layers of clouds. As we have just seen in the case of comparison with the results of MO MSU it is very important. For validation aims, we are going to use the data of ground-based measurements that will be provided by stations of Baseline Surface Radiation Network. For testing of developed algorithms and software corresponding data from synchronised SEVIRI measurements after the end of the MSG satellite commissioning phase will be used. It is assumed that Web version of the UMMS will be also accessible via the Internet.

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